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# An Evaluation DEM Accuracy Acquired Using a Small Unmanned Aerial Vehicle Across a Riverine Environment

**Entwistle N.S., Heritage G.L.**

***Abstract-*** **Fluvial systems offer a challenging and varied environment for topographic survey, displaying a rapidly varying morphology, diversevegetation assemblage and varying degree of submergence. Traditionally theodolite or GPS based systems have been used to capture cross-section and break of slope based data which has subsequently been interpolated to generate a topographic surface. Advances in survey technology has resulted in an improved ability to capture larger volumes of data with infrared terrestrial and aerial LiDAR systems capturing high-density (<0.02m) data across terrestrial surfaces but instruments are expensive and cumbersome and fail to survey through water.**

**The rise of Structure from Motion (SfM) photogrammetry, coupled with unmanned aerial vehicles (UAVs), has potential to rapidly record information needed to derive elevation data at reach scale with sub decimetre density. The approach has the additional advantage over LiDAR of seeing through clear water to capture bed detail, whilst also generating orthorectified photographic mosaics of the survey reach. However, the accuracy of the data has received comparatively little attention. Here we present a survey protocol for UAV deployment and provide a reach scale comparison between a Terrestrial LiDAR Survey (TLS) and SfM UAV survey on the River Sprint near Kendal in England.. Comparative analysis of elevation data between TLS and SfM suggest comparable accuracy and precision across terrestrial surfaces with error lowest over solid surfaces, increasing with vegetation complexity. Submerged SfM data captured bed levels generally to within ±0.2 with only a weak relationship recorded between error and flow depth.**

***Index Terms*— DEM, LiDAR, SfM, UAV.**

## I. INTRODUCTION

Photogrammetry is a remote sensing technique that has undergone significant recent developments related to the emergence of new computer vision algorithms, notably the workflow technique called Structure-from-Motion (SfM photogrammetry). These innovations facilitate the utilization of this technique by non-specialists through a step by step SfM workflow to enable the production of high-resolution 3D terrain models and orthophotographs [1, 2, 3 4], however camera lens distortion can result in doming or dishing surface model distortions [5].Accurate terrain data are helping to equip researchers to study geomorphological form (and process change in dynamic environments [6]. Key to such studies is the surveys to achieve sufficient accuracy and precision to resolve changes at relevant spatial scales within a consistent reference frame so they can be confidently repeated and compared [7].

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There has been a recent proliferation in publications assessing the accuracy of SfM-derived data studies (for example [3, 8,9,10, 11, 12, 13, 14, 15]. Reported accuracies vary widely, from <0.1 m to over 1 m, reflecting with error attributed variously to images resolution/quality, image distortion, camera calibration and to the characteristics of the surface being measures particularly with respect to vegetation.

This paper adds to the evaluation process outlining a survey protocol for UAV deployment to generate reach scale morphologic mapping of a highly variable natural environment. The study site was an active wandering channel of the River Sprint near Kendal in England and this paper provides a comparison between a Terrestrial LiDAR Survey (TLS) and SfM UAV survey across a variety of natural surfaces.

## II. STUDY SITE

The River Sprint is a small temperate alluvial river in the UK. It has aa catchment area of around 35 km$^2$ joining the River Kent just south of Burneside. Average rainfall in the catchment is very high for the UK, amounting to 2,018 mm per year. Flow has been recorded at Sprint Mill, located just upstream of the confluence with the River Kent since 1976. Median flow there is around 1.0 m$^3$/s, whilst the Q95 (low flow) is around 0.17 m$^3$/s and the Q10 (high flow) is around 4.8 m$^3$/s. The land use and habitat of the catchment is >80% grassland, approximately 10% mountainous, heath or bog with around 6% woodland.

The Upper catchment of the River Sprint has been strongly influenced by glaciation creating upland moorland dissected by U shaped glacial troughs containing variable levels of glacial and fluvio-glacial infill as valley floor deposits. Post-glacial fluvial activity has created a number of steep headwater streams above the Sadghyll gravel trap flowing down onto Brownhowe Bottom, a flatter plateau area formed of glacial and fluvio-glacial deposits and contemporary peat. A Glacial and fluvio-glacially cut bedrock channel then connects Brownhouse Bottom and the Sadghyll gravel trap. Downstream of the gravel trap the valley bottom exhibits a near-continuous alluvial valley bottom through to Gurnal Bridge.

The headwater valleys of the Upper Sprint are characterised by moderately steep bedrock influenced single thread boulder step-pool channels and shorter confined bedrock cascade reachesbefore discharging onto the flatter wider fluvio-glacial valley floor immediately upstream of the Sadghyll gravel trap.

This abrupt valley floor widening creates a rapid transition zone where transport energy drops off rapidly resulting in the development of a long (>750 m) depositional zone characterised by a wide coarse sediment valley floor dissected by multiple active and inactive distributary channels (Fig 1). The present active zone occupies less than a quarter of the valley floor but switching of channels has occurred in the historic past as evidenced by well-preserved palaeo-channels and future channel switching is possible under high flows (although this has been restricted by the use of boulder riprap bank protection along outer bends of the present active channel).

The Boulder weir structure creating the gravel trap has been constructed across the valley floor linking two low terraces. Originally this would have created a sediment storage volume up to 2.5 m deep across 50 m of channel and valley floor extending over 100 m upstream (> 50,000 m$^3$). This volume has been completely filled by coarse sediment and material is now stored to the level of the weir crest allowing coarse sediment to pass freely downstream.

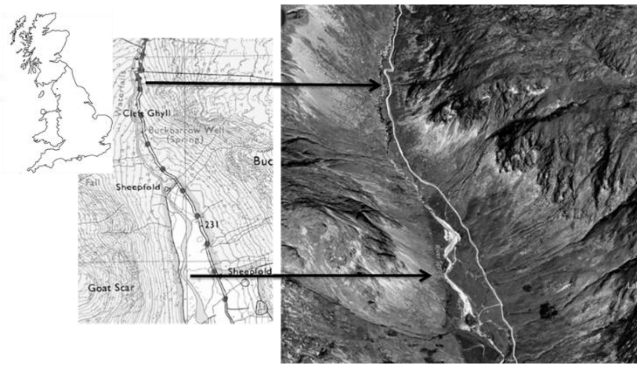


*Fig 1. Location of the Sadghyll study site on the River Sprint (map © Ordnance Survey).*

## III. Methods

### A. Data Acquisition

A quadcopter unmanned aerial vehicle (UAV) was used to obtain multiple aerial photographs of each study reach using a high-resolution (14 Megapixels, at resolution 4384×3288 and 1080p HD recording) narrow field of view (85°) digital camera, mounted on a remotely operated 3 axis gyroscopic gimble to allow for optimal stability during flight. The camera was set to acquire time-lapse photography at intervals of three seconds in order to ensure sufficient spatial coverage and substantial image overlap, following the principles of Micheletti *et al*. [1]. Camera settings were optimized for each study reach, these included: picture quality, ISO levels, exposure compensation, white balance, and capture format.

The DJi UAV quadcopter was operated remotely by a qualified drone pilot using an operating frequency of 2.4GHz while the onboard camera was controlled from a connected mobile device and positioned facing directly downwards for data acquisition, capturing images at or near to nadir. The UAV was flown at uniform height (~25 m) to allow for accurate reconstruction during post-processing, although external influences such as weather turbulence resulted in a ±0.5 m margin. This altitude proved optimal for survey of a river and floodplain width around 200 m.

Survey georeferencing was achieved through a system of 29 ground control points (GCPs) surveyed using Total Station EDM theodolite (Fig 2) within a 0.1 km$^2$ area. The GCPs were distributed systematically within each reach to maximize their effectiveness in post-processing [16].

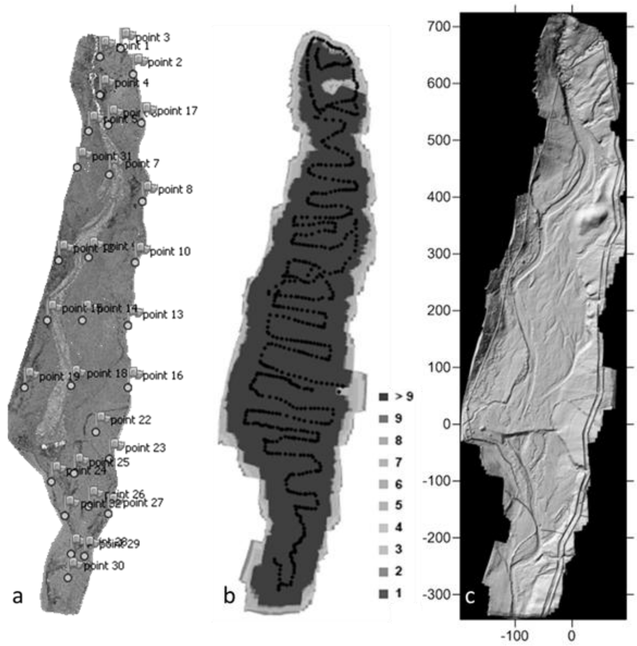


*Fig2. Ground control point distribution and final orthophoto (a), camera locations and image overlap (b) and Digital Elevation Model (c) of the Sadghyll study site.*

### B. Post-processing

With photographs captured following photogrammetric standards suggested by Eisenbeiß [17], all post-processing was conducted on Intel i7 desktop computer with 64Gb RAM using Agisoft Structure from Motion (SfM) software. Images were mosaicked together using a SfM photogrammetrical approach as detailed by Micheletti *et al.*[1], whereby rasterized three-dimensional representations are constructed from two-dimensional (camera calibrated) images [18]. Images were manually and automatically inspected for quality and out-of-focus, with off-nadir or blurred photographs discarded before the remaining images were aligned in the SfM software through identification of conjugate points common in several photographs of a given area. This is propagated over the entire reach.

Within each aerial image, systematically distributed Ground Control Points (GCPs) were manually assigned their corresponding theodolite-derived coordinate in the SfM software allowing the photographs to be realigned and scaled based on local theodolite coordinate system. Dense point clouds were built from the georectified imagery using aggressive depth filtering ignoring unnecessary micro-scale details during processing, thereby decreasing computational resources [19]. Geometry was constructed using a height field approach and disabled interpolation yielded geometry based on points constructed in the dense point cloud. A textured model was then built using previously computed geometry, where raw image pixels were draped over the geometric model to yield a DEM. In addition, this process provided fully orthorectified aerial images of each study reach (Fig 2a).

To support comparative accurate data both the Lidar and UAV approach followed the protocol set by Heritage and Hetherington [20] whereby the channel and surrounding floodplain were surveyed to a single project coordinate system using the independent theodolite points. The Lidar survey was facilitated by a LMS-Z390 scanning laser manufactured by Riegl Instruments and data from each individual scan (total 5 scans) were recorded in the scanner coordinate system that varies with each setup. The Lidar datasets recorded range distance, relative height, surface colour and reflectivity. The independent field theodolite tie points were measured for both Lidar and UAV survey with a prism reflector in the field without the pole attachment for increased accuracy. Theodolite survey accuracy was ±0.002 m.The resultant meshed set of laser scans and UAV datasets were clipped to remove unwanted information such as distant points, overhanging tree canopy and any spurious aerial data points returned from aerosols or raindrops.

## IV. Results

### A. General Model Build

Summary statistics of the general survey for thestudy site are presented in Table I. It is clear that the SfM technique is able to locate and georeferenced GCP sites to a high level of accuracy (± 0.01 m) comparative to James and Robson [9] who reported errors between 0.01 and 0.015 m. With data point density between terrestrial and aerial LiDAR [1]. Survey point density may be controlled within the SfM software up to the pixel resolution on the captured images, however, higher density point clouds require considerably increased post-processing time and computing power. The key advantage with a sUAV survey is that field time is much lower when compared with terrestrial LiDAR survey (Table 1) and survey resolution is much higher than that of aerial Lidar.

| | sUAV | LiDAR |
|---|---|---|
| *Model extent* | 0.12 km$^2$ | 0.02 km$^2$ |
| *Images used* | 662 | |
| *Scan positions* | | 5 |
| *Point cloud points* | 53,872,817 | 21,524,912 |
| *Points per m$^2$* | 607 | 911 |
| *Field survey time* | 3 hours | 2.5 hours |
| *Post-processing time* | 8 hours | 6 hours |
| *x error* | 0.018 | 0.015 |
| *y error* | 0.016 | 0.014 |
| *z error* | 0.014 | 0.011 |
| *Combined error* | 0.028 | 0.018 |

*Table I. Statistics relating to the sUAV and Lidar survey of the Sadghyll study site on the River Sprint*

### B. Data coverage and error

Wider survey differences were computed by comparing the sUAV and Lidar surfaces (Fig 4). The principle positive error is associated with Lidar shadowing and negative error is due to failure of the LiDAR to penetrate water given the 1500 $\mu m$ wavelength. Red Green Lidar could potentially overcome this issue but presently this is not legal in the UK [21].

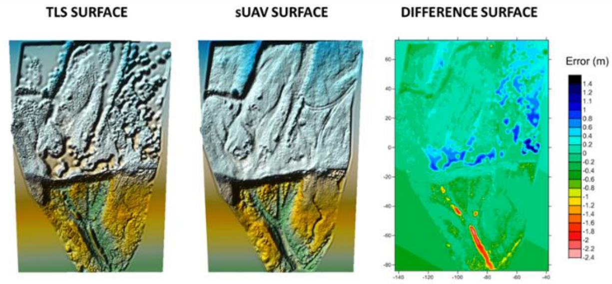


*Fig 4. Comparative difference surface of terrestrial LiDAR and sUAV derived elevation data for the Sadghyll study site*

It is clear from the summary statistics (Table II) that the average error across subaerial zones remains in the region of ± 0.04 m.

| | |
|---|---|
| "Number of values" | 4,562,231 |
| Mean error | 0.04 |
| Standard deviation | 0.21 |
| Skew | 4.70 |
| Kurtosis | 50.36 |

*Table II. sUAV difference statistics compared to baseline terrestrial LiDAR.*

The difference pattern was investigated further through extraction of data across similar surfaces. An initial feature classification was conducted on the orthophoto of the site using image colour as a differentiator (Fig 5). The classification successfully identified grassland, dry and wet gravel, submerged areas and small pockets of low shrubs (Fig 6).

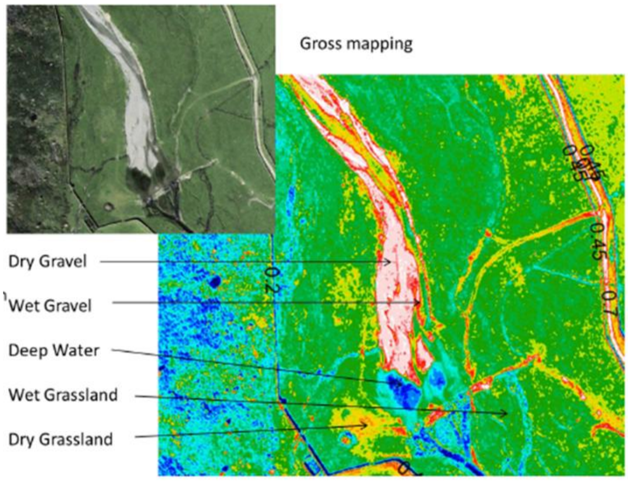


*Fig 5. Variable surface character across the Sadghyll study site.*

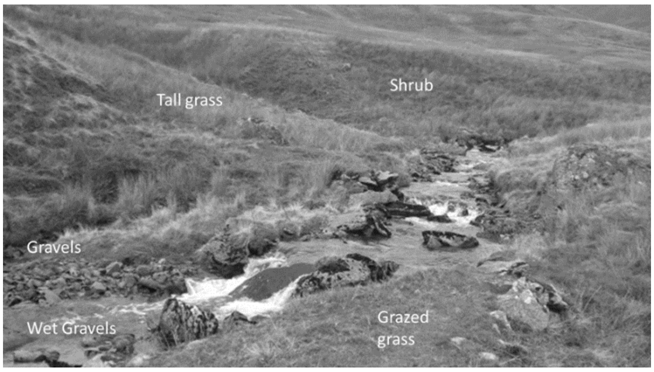


*Fig 6. Vegetation and surface character on the Sadghyll study site.*

### C. Variability in surface error

The sUAV and Lidar accuracy were also confirmed using a theodolite across hard surfaces at the gravel trap weir. Fig 7a shows the section across the weir crest. The sUAV error is low over the weir capturing wet and dry surfaces with equal accuracy, in contrast the Lidar performs well across the dry areas but fails to collect data where flowing water is present. Both the Lidar and sUAV data after chainage 70 m plot above the theodolite points by 0.2 - 0.3 m this is due to both techniques recording tall grass vegetation surface whilst the theodolite records the true ground elevation. A transect taken from the sUAV and Lidar data recorded across the cobble blockwork weir face (Fig 7b) show good general agreement with the majority of readings within 0.1 m of each other.

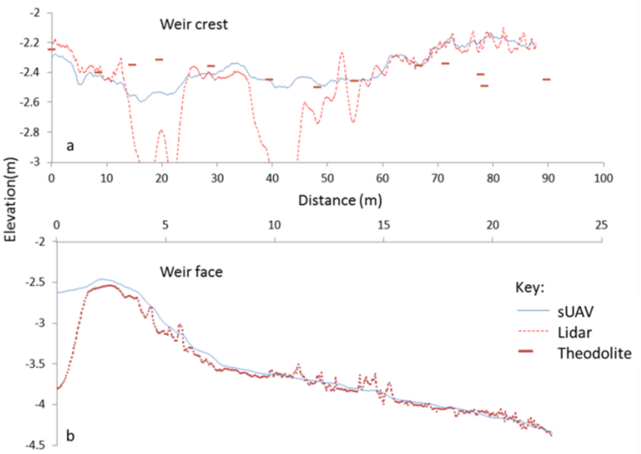


*Fig 7. Comparative measures (theodolite) SfM and LiDAR) of hard surfaces at A) weir crest and B) a dry transect down the weir face at the Sadghyll gravel trap on the River Sprint.*

### D. Gravel surface error

Exposed gravels were investigated within a 2x2 m patch (Fig 8) with data points from the SfM survey at Sadghyll compared with comparative points captured by the terrestrial LiDAR survey. Fig 9 shows that 84.14% of Lidar data fall within 0.2 m error and 64% within 0.01. Comparatively sUAV error are 86.37% and 71.78% fall within 0.2 m and 0.1 m respectively (Fig 9).

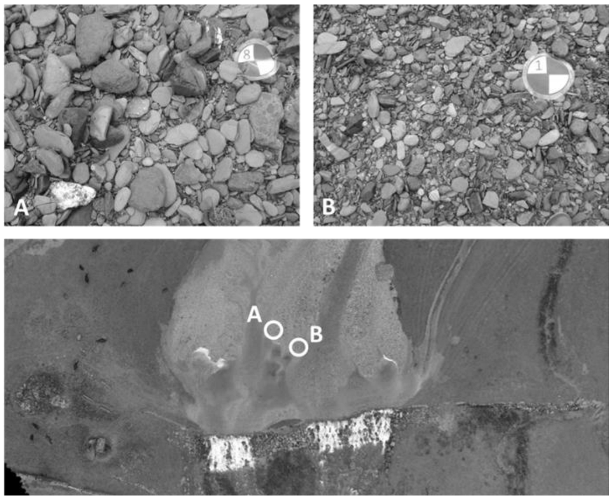


*Fig 8. Gravel locations for comparative analysis between Lidar and SfM on the River Sprint.*

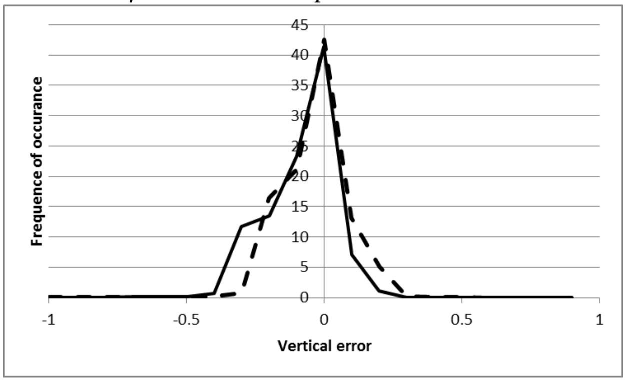


*Fig 9. Measured Lidar (Solid) and SfM (dots) model estimate elevation difference across R. Sprint gravel surface.*

### E. Vegetation induced error

Error associated with differing vegetation found at Sadghyll was investigated (Fig 10). High error is associated to penetration issues for both survey methods, where the sUAV and the Lidar both record the surface of the vegetation, with the theodolite staff recoding true ground. Shrubs have good surface coverage with little sUAV and Lidar penetration.

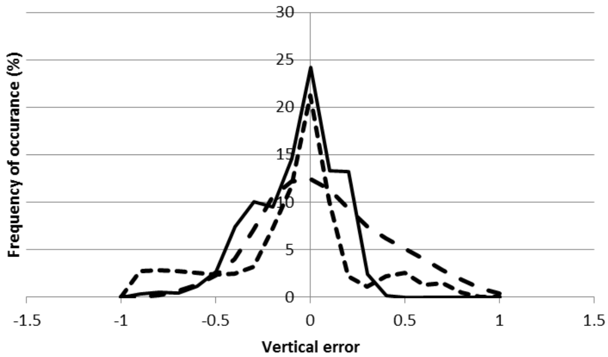


*Fig 10. Measured Lidar and SfM model estimate elevation difference across wet grass (solid), dry grass (dashed) and shrub (dots) vegetation types on the River Sprint.*

### F. Error associated with submerged surfaces

The effect of pooling water in both shallow <0.3 m and deeper <1 m pools were investigated in three locations within the Sadgill reach with the results combined in Fig 11. Whilst the Lidar wavelength was absorbed, sUAV data captured data from the river bed allowing direct comparison between theodolite recorded depth and SfM sUAV bed depth. Carbonneau et al. [22]suggest that for bathymetric measurements from remote sensing platforms a correction factor should be applied, however, for this accuracy assessment this has not been applied. The agreement in Fig 11 is strong with an $R^2$of 0.9

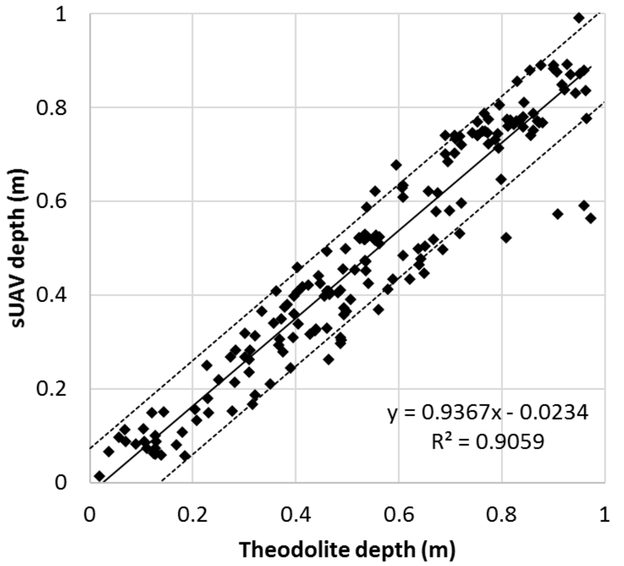


*Fig 11. Measured (theodolite) and SfM model estimate depth discrepancy – depth relationship for the River Sprint at Sadghyll.*

## V. Discussion

A simple low cost sUAV was deployed to calculate high resolution topography in the English Lake District on the River Sprint. The spatial sUAV data are researched using SfM methods with the precision tested against know accuracies in Lidar technology (Heritage and Hetherington, 2007) on wet and dry vegetation, water, and small scale gravel texture investigated all for inaccuracies.Results are shown to be comparable with existing findings in the use of sUAV technology and SfM-photogrammetry for quantifying fluvial topography [3, 23, 24, 25], and are approaching those possible with TLS for exposed areas [20, 26, 27].

The use of sUAV and terrestrial Lidar as remotely sensed platforms for data collection can significantly improve assessments in fluvial environments over that of airborne Lidarand therefore facilitate research at reach scales where high resolution is required. This research was conducted over a 0.12$km^2$ area using the sUAV and a 0.02 $km^2$ area from the terrestrial LiDAR with similar field time required for each survey. This suggests that sUAV approaches are considerably more efficient at obtaining data most notably due to the ability to capture wide swathes of imagery and the lack of significant shadowing issues.

sUAV technology thus provides an improved field survey time than that of Lidar, in addition to considerable reduction in technological and software costs. This presents a significant shift in the ability to conduct detailed fluvial research across large areaseven when precise spatial information is of great importance. Furthermore rapid sUAV mapping and subsequent SfM photogrammetry provides the platform for data capture at a variety of scales.With camera lens improvements flight heights can be increased, resulting in a greater field of view, allowing larger areas to be overed whilst maintaining point data accuracy and point density.

## VI. Conclusion

The use of high resolution remote sensing data from ansUAV platform represents an encouraging technique for quantifying the topography of fluvial environments at the meso-habitat scale. From the results presented here, key advantages include high spatial resolution outputs which facilitate feature identification andtopographic surface generation and additional opportunity exists to characterize surface sedimentology and biotope distribution. In addition, the rapid, flexible nature of the survey allow for repeatable and relatively inexpensive resurvey offering opportunity to study geomrohic change across a range of spatial scales.

As with all line of site survey techniques SfM photogrammetry can be limited in areas where this cannot be achieved, for example under tree canopy or through turbid or turbulent water with average error across subaerial zones in the region of ± 0.04 m. Operational constraints with the UAV result in an operating environment with a wind speed below 9 m/s (18 knots) and a flight time of 25 minutes per battery, although technological developments are decreasing these constraints.

Low-cost, user-friendly SfM photogrammetry offers interesting new perspectives in the fields of coastal and fluvial geomorphology requiring high-resolution topographic data. The technique combines the advantages of the reproducibility of GPS topographic surveys and the high density and accuracy of airborne LIDAR, but at very advantageous cost compared to the latter.

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## References

[1] N. Micheletti, J. H. Chandler, and S. N. Lane., 2015. Structure from motion (SFM) photogrammetry. IN: Clarke, L.E. and Nield, J.M. (Eds.) Geomorphological Techniques (Online Edition). London: British Society for Geomorphology. ISSN: 2047-0371, 2015. Chap. 2, Sec. 2.2.

[2] Westoby, M. J., J. Brasington, N. F. Glasser, M. J. Hambrey, and J. M. Reynolds. "'Structure-from-Motion'photogrammetry: A low-cost, effective tool for geoscience applications." *Geomorphology* 179 2012, pp300-314.

[3] M.A. Fonstad, J.T. Dietrich, B.C. Courville, J.L. Jensen, and P.E. Carbonneau. "Topographic structure from motion: a new development in photogrammetric measurement." *Earth Surface Processes and Landforms* 38, no. 4. 2013, pp 421-430.

[4] Smith, M. W., J. L. Carrivick, and D. J. Quincey. "Structure from motion photogrammetry in physical geography." *Progress in Physical Geography* 40, no. 2. 2016, pp247-275.

[5] P.E. Carbonneau, and J.T. Dietrich. "Cost- effective non- metric photogrammetry from consumer- grade sUAS: implications for direct georeferencing of structure from motion photogrammetry." *Earth Surface Processes and Landforms* 42, no. 3. 2017, pp473-486.

[6] J.S. Aber, I. Marzolff, and J. Ries. *Small-format aerial photography: Principles, techniques and geoscience applications*. Elsevier, 2010.

[7] K.L. Cook. "An evaluation of the effectiveness of low-cost UAVs and structure from motion for geomorphic change detection." *Geomorphology*, 278. 2017, pp195-208..

[8] S. Harwin, and A. Lucieer. "Assessing the accuracy of georeferenced point clouds produced via multi-view stereopsis from unmanned aerial vehicle (UAV) imagery." *Remote Sensing* 4, no. 6 2012, pp1573-1599.

[9] M.R. James, and S. Robson. "Straightforward reconstruction of 3D surfaces and topography with a camera: Accuracy and geoscience application." *Journal of Geophysical Research: Earth Surface* 117, no. F3, 2012.

[10] M.J. Westoby, J. Brasington, N.F. Glasser, M.J. Hambrey, and J.M. Reynolds. "'Structure-from-Motion' photogrammetry: A low-cost, effective tool for geoscience applications." *Geomorphology* 179 2012, pp300-314.

[11] T.N. Tonkin, N.G. Midgley, D.J. Graham, and J.C. Labadz. "The potential of small unmanned aircraft systems and structure-from-motion for topographic surveys: A test of emerging integrated approaches at Cwm Idwal, North Wales." *Geomorphology*, 226, 2014, pp 35-43.

[12] M.W. Smith, and D. Vericat. "From experimental plots to experimental landscapes: topography, erosion and deposition in sub- humid badlands from structure- from- motion photogrammetry." *Earth Surface Processes and Landforms* 40, no. 12, 2015, pp1656-1671.

[13] G. Brunier, J. Fleury, E.J. Anthony, A. Gardel, and P. Dussouillez. "Close-range airborne Structure-from-Motion Photogrammetry for high-resolution beach morphometric surveys: Examples from an embayed rotating beach." *Geomorphology*, 261, 2016, pp 76-88.

[14] M.R. James, and J.N. Quinton. "Ultra- rapid topographic surveying for complex environments: the hand- held mobile laser scanner (HMLS)." *Earth surface processes and landforms* 39, no. 1, 2014, pp138-142.

[15] A. Stumpf, J.P. Malet, P. Allemand, M. Pierrot-Deseilligny, and G. Skupinski. "Ground-based multi-view photogrammetry for the monitoring of landslide deformation and erosion." *Geomorphology*, 231, 2015, pp130-145.

[16] T.N. Tonkin, and N.G. Midgley. "Ground-control networks for image based surface reconstruction: an investigation of optimum survey designs using UAV derived imagery and structure-from-motion photogrammetry." *Remote Sensing* 8, no. 9, 2016, pp786.

[17] H. Eisenbeiß, H., UAV photogrammetry 2009. ETH ZURICH (Doctoral dissertation).

[18] D. Scaramuzza, A. Martinelli, and R. Siegwart. "A flexible technique for accurate omnidirectional camera calibration and structure from motion." In *Computer Vision Systems, 2006 ICVS'06. IEEE International Conference on*, pp. 45-45. IEEE.

[19] Manual, Agisoft PhotoScan User. "Professional edition." *Aplastic Anemia (Hypoplastic Anemia)*, 2014, (http://www.agisoft.ru)

[20] G.L. Heritage, and D. Hetherington. "Towards a protocol for laser scanning in fluvial geomorphology." *Earth Surface Processes and Landforms* 32, no. 1, 2007, pp66-74.

[21] S. Pe'Eri, and W. Philpot. "Increasing the existence of very shallow-water LIDAR measurements using the red-channel waveforms." *IEEE Transactions on Geoscience and Remote Sensing* 45, no. 5, 2007, pp1217-1223.

[22] P.E. Carbonneau, S.N. Lane, and N. Bergeron. "Feature based image processing methods applied to bathymetric measurements from airborne remote sensing in fluvial environments." *Earth Surface Processes and Landforms* 31, no. 11, 2006, pp1413-1423.

[23] J. Lejot, C. Delacourt, H. Piégay, T. Fournier, M- L. Trémélo, and P. Allemand. "Very high spatial resolution imagery for channel bathymetry and topography from an unmanned mapping controlled platform." *Earth Surface Processes and Landforms* 32, no. 11, 2007, pp1705-1725.

[24] S. Harwin, and A. Lucieer. "Assessing the accuracy of georeferenced point clouds produced via multi-view stereopsis from unmanned aerial vehicle (UAV) imagery." *Remote Sensing* 4, no. 6, 2012, pp1573-1599.

[25] A. S. Woodget, , P.E. Carbonneau, F. Visser, and I.P. Maddock. "Quantifying submerged fluvial topography using hyperspatial resolution UAS imagery and structure from motion photogrammetry." *Earth Surface Processes and Landforms* 40, no. 1, 2015, pp47-64.

[26] D.J. Milan, G.L. Heritage, A.R.G. Large, and N.S. Entwistle. "Mapping hydraulic biotopes using terrestrial laser scan data of water surface properties." *Earth Surface Processes and Landforms* 35, no. 8, 2010, pp918-931.

[27] S.G. Bangen, J.M. Wheaton, N. Bouwes, B. Bouwes, and C. Jordan. "A methodological intercomparison of topographic survey techniques for characterizing wadeable streams and rivers." *Geomorphology*, 206, 2014, pp343-361.